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Development of the regulating device for the liquid phase of gas well fluid

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Abstract

The paper is aimed to numerical research of operating processes and development of gas-distributing systems calculating method based on the control volume method, with the purpose to develop a new device for regulating the flow of liquid phase of the gas well fluid. The calculations of structural parameters are carried out; on their basis the recommendations on developing liquid phase regulating device are obtained. Based on the research results, structural parameters and device characteristics for various operation modes for different media are obtained. The implementation of the research results is described.

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Keywords: regulating device; CFD; control volume method; oil and gas extraction technology

1. Introduction

For providing gas recovery factor increase during extraction, specific throttling devices are used. Such devices are aimed to provide uniform formation depletion, equalizing of the inflow towards the horizontal wells, extraction control in every zone, and breakthrough dead time.

To avoid potential problems, caused by water breakthrough in gas wells, the installation of the systems regulating inflow for equalizing depletion in multiple-zone systems is used. Unexpected water breakthrough in gas wells leads to such serious consequences as reduction of the average life of the well and its shutting-in after the partial depletion. Finally, it results in the decrease of the profit which the well could provide theoretically **Ошибка! Источник ссылки не найден.**. Uniformed formation depletion is shown in Fig. 1.

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However, water breakthroughs in production wells in high-permeability formations, at the well's heel, and at close water contact occur very often (Fig. 2). When the breakthrough is likely to happen in a particular zone of the production well, it is necessary to plug it or minimize water entry into the gas extraction system. For this purpose, various devices regulating liquid phase of the well fluid have been developed. In the case when a horizontal well is in a heterogeneous formation, the probability of the fast water breakthrough along the high-permeability zones is high. Water breakthroughs can result in the well shut-in and its workover. From there, to solve these problems, the inflow control devices, which equalize the inflow profile off, block water breakthrough and provide the full extraction of the well resources, are developed [1,2].

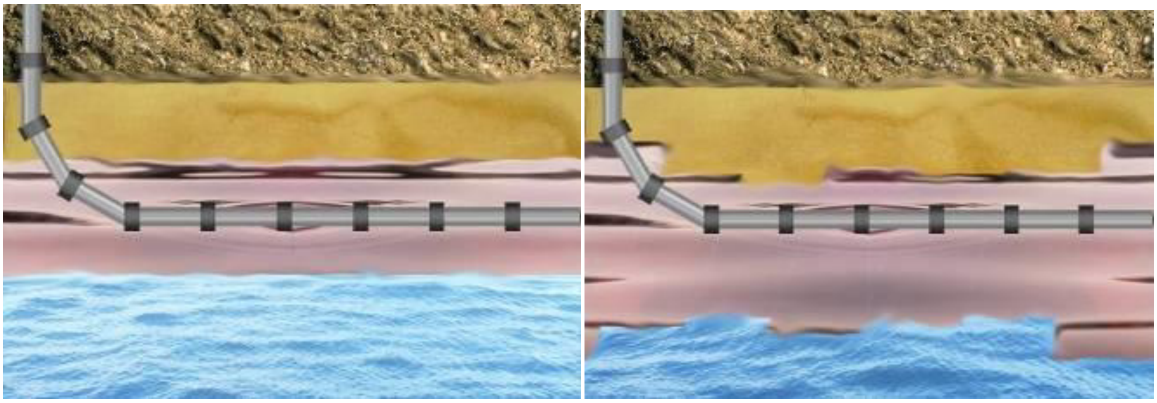

Fig. 1. Uniform inflow profile in a well

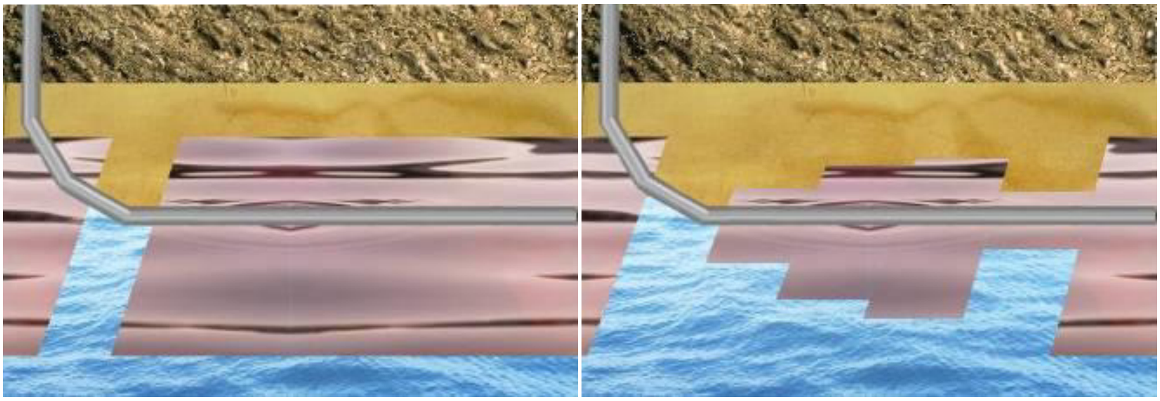

Fig. 2. Water breakthrough in a well in the case of open hole/clad injection

Until recently, the following devices have been used in oil and gas extraction: gas fluid flow limiter and water flow regulating device, limiting the flow of liquid and gaseous working fluids. From there, it seems very important to develop a device, aimed in regulating two-phase fluid by blocking the liquid phase and let gaseous phase flow almost easily [3,4]

Pressure differential and device hydraulic characteristics should be in the range, providing gas extraction during normal operating and limiting the water flow during the breakthrough. For this purpose pressure drop can be reached by high hydraulic resistance of the flow path itself [1]. Increase of hydraulic resistance is provided by repetitive change of the flow direction, flows confluence and separation. Pressure change should be even along the device [5,6].

2. Study subject

The regulation device for the liquid phase flow is developed for unrestricted passage of the extracted gas in the case of normal well exploitation and for sharp limiting the flow of the passing liquid (water) in the case of its probable breakthrough from the injection wells.

The structure of the flow regulating device incorporates two tubes – an outer and an inner one, and the gap between them where the grid of ring channels with the tandem labyrinth edges, is located. The layout of the regulatory device is shown in Fig. 3. Input and output openings of the neighbouring ring channels seal edges are located in diametrical opposition to each other. Every ring channel is uniform with equally-spaced location of seal edges relative to the previous channel. Three-dimensional model of the liquid phase regulating device with the cover and without it is shown in Fig. 4. In such device version labyrinth seal edges have a form of triangular lugs in a square section ring channel, but can also have another form in accordance with process requirements. Every following grummet wedge is located on the opposite channel wall of the operating media path.

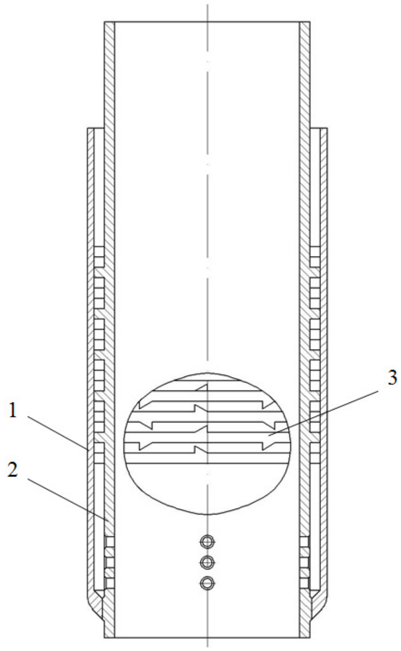

Fig. 3. Liquid phase regulating device of multi-phase operating medium: 1 – outer tube; 2 – inner tube; 3 – labyrinth edges of the stop

The body is designed in the form of two tubes (an outer and an inner one), placed coaxially and bound with each other, the working channel located between the tubes. In this case, the channels can also have a form of rectangular, round, square or any other section. The choice of the labyrinth elements height and their quantity in the channel depends on the device operating conditions.

Operation principle of the liquid phase regulating device is based on the change of the flow direction along the operating medium path. Having entered the ring channels grid, the flow runs into the obstructions (edges of the labyrinth seal edges), which is equal to a great number of series and parallel resistance. In this case, gaseous fluid passes almost unconstrained thanks to the isothermal gas expansion effect. Thus, pressure drop occurs gradually and uniformly along the device full length.

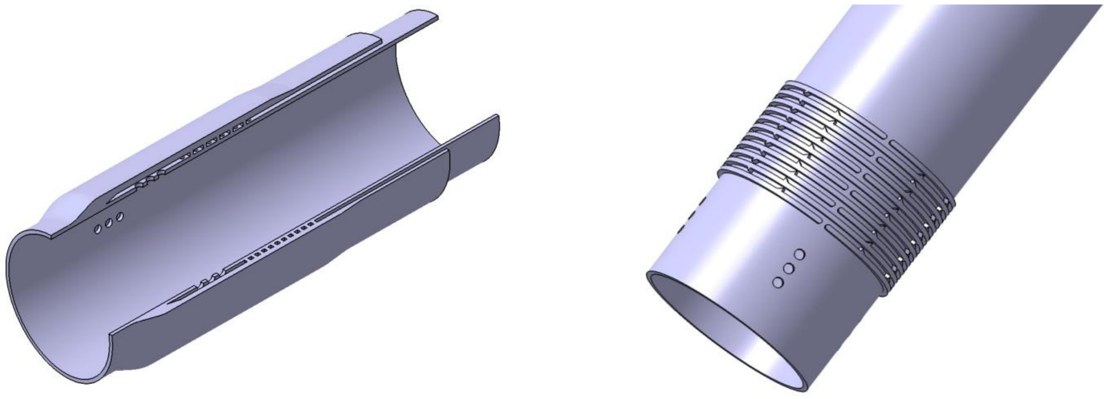

Fig. 4. Liquid phase regulating device of multi-phase operating medium

For defining regulating device structural characteristics, design analysis of various alternatives of the liquid phase regulating device modification, differing by the number of edges and the edges relative height was carried out (Fig. 5). In calculations, the number of edges varied and was equal to 5, 7 and 11, which corresponds to the angle between edges, α= 30°, 22.5° and 15°. The edges height is a relative value a/b= 0.5; 0.6; 0.7; 0.8 and 0.9 from the channel run-in clearance, which corresponds to the edges height 1.5; 1.8; 2.1; 2.4; and 2.7 mm.

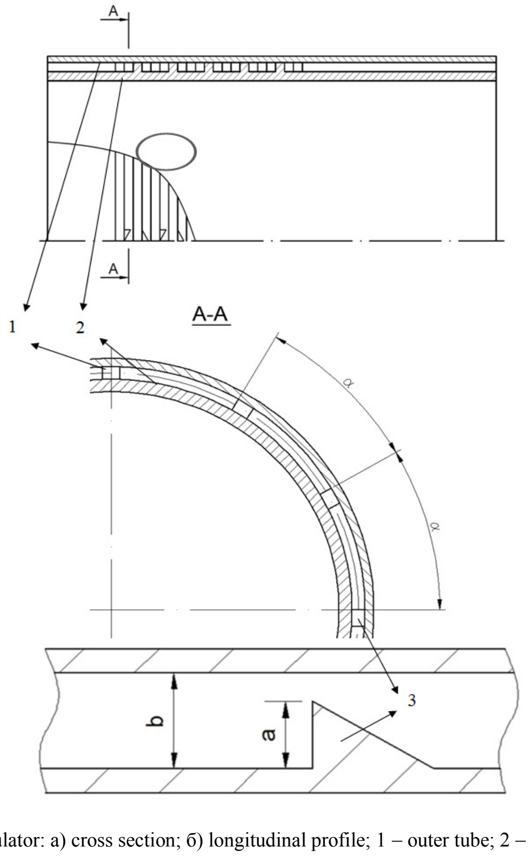

Fig. 5. Liquid phase flow regulator: a) cross section; б) longitudinal profile; 1 – outer tube; 2 – inner tube; 3 – throttle edges

3. The calculation of the well fluid liquid phase regulating device

To simulate operation modes of the liquid phase regulating device, simulation models have been created, reflecting the characteristics of the structure under consideration. To simulate the regulating device 2 independent methods of calculation were used. For a quick simulation of various designs a variant of the control volume method (CVM) for the channel simulation systems was used [7,8]. To confirm the results obtained by the CVM, computational fluid dynamics (CFD) simulation was conducted [5,6].

In accordance with a complex spatial geometry for rapid analysis based on the CVM, design diagrams were presented in the form of spatial grids (3-D network). Analytical models were simulated for different numbers of edges along the length of the channel (5, 7 and 11 edges, respectively) and different number of channels (1 to 10). The flow section of the liquid phase flow regulating device for 10 channels with 5 edges on them is shown in Fig. 6. This model is represented in the form of 106 nodes and 120 links (channels). The initial CVM data set requires the specifications (size of channels passage sections, length and hydraulic resistance of channels).

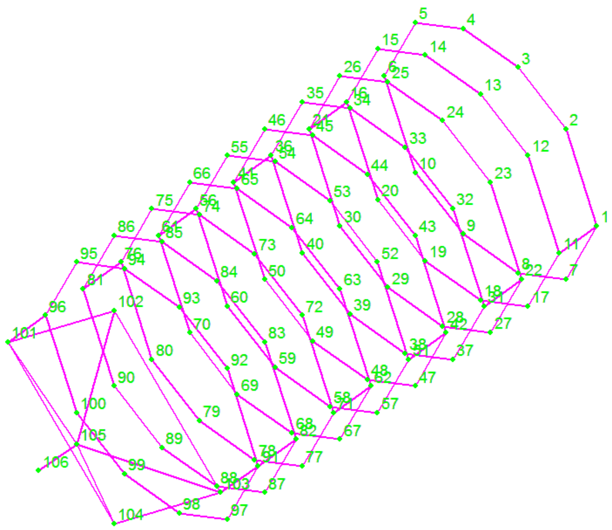

Fig. 6. Hydraulic model of the liquid phase flow regulating device

The calculations were made separately for liquid and gaseous phase, which provided to obtain “pure” effect of the flow regulation. Water under standard conditions was considered as liquid phase, and methane, with properties described by perfect gas equation was considered as gaseous phase.

Resistance factors were chosen on the basis of data [7] and referent CFD calculations [5,6]. Herein, CFD simulations proved the hypothesis about gas flow isothermal expansion after working elements and let us correct resistance factors for the closely-spaced edges, influencing each other. However, CFD simulation cannot provide fast simulating of a plenty of the device modification variants, besides, during CFD calculation it is not always possible to obtain steady-state solution to the problems of high dimension. Simulation of the system parameters using CVM allowed to quickly carry out a series of calculations to determine the characteristics of the different limiter designs for operation modes for liquid and gaseous media.

3.1. Liquid phase flow calculation

In the liquid phase simulation, was made an assumption that the water density is constant and equal to 1000 kg/m^3. In the simulation of hydraulic resistance with the help of CVM was made an assumption that the flow regulating device operates in the Reynolds numbers self-similarity, and the resistance values can be taken as constant. This assumption was tested using CFD simulation of the regulator specific areas [5], [6]. Comparison of the results of hydraulic calculation using CVM and the results of CFD simulation for design with α = α=30°, a / b = 0.8 is shown in Table 1. As can be seen from the table, the maximum relative results deviation was equal to 7%, which is connected with the hydraulic resistance coefficient band fault from Reynolds numbers self-similarity zone and its slight change [9].

Table 1. Comparison of the CVM and CFD calculation results (α=30°, a/b = 0.8)

Flow rate, kg/s	Pressure drop (CFD), MPa	Pressure drop (CVM), MPa	Inaccuracy, %
0.00463	0.008074	0.007501715	7.088003
0.009259	0.031544	0.030006859	4.873007
0.018519	0.124253	0.120027435	3.400775
0.027778	0.276571	0.270061728	2.353563
0.037037	0.487889	0.480109739	1.594473
0.046296	0.758602	0.750171468	1.111325
0.055556	1.088513	1.080246914	0.759393

As a result of numerical simulation of water flow through the liquid phase flow regulating device for the well fluid with the help of the developed CVM modification, flow dependence on the pressure drop is obtained. Comparison results of the obtained characteristics and data of CFD simulation are given in Fig. 7. As it can be seen from the figure, relative CVM results deviation from CFD solution does not exceed 7%, while maximum deviation is observed in the Reynolds numbers self-similarity.

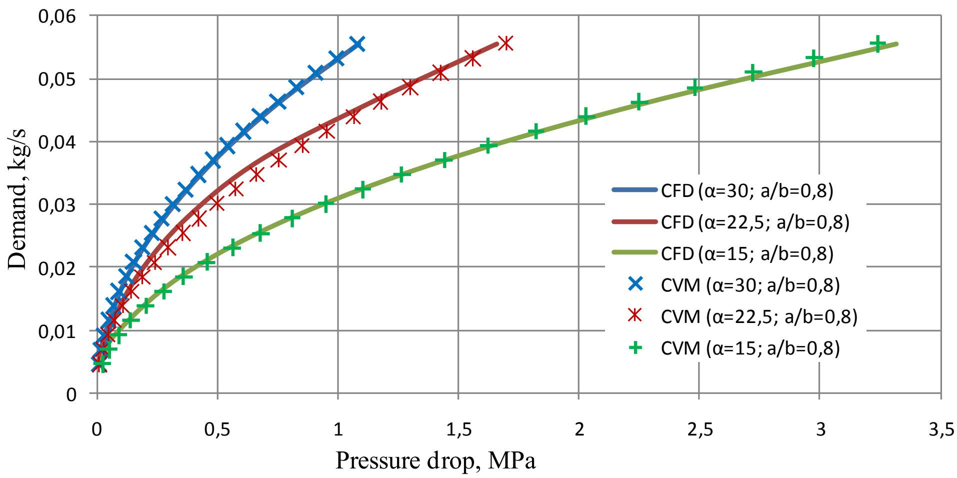

Fig. 7. Flow dependence on the pressure drop

3.2. Gaseous phase flow calculation

During CVM simulation was accepted the assumption about isothermal gas flow, that was proved with the help of CFD simulation of the specified area of the device considered [5,6]. Numerical simulation was carried out for constant pressure 14 MPa at the input and various pressure values at the output of the device. Comparison of calculation results, obtained with the help of the developed control volume method and CFD simulation results is given in table 2. As it can be seen from the table, results deviation was less than 3 %.

As a result of numerical simulation of methane flow through the well fluid liquid phase flow regulating device with the help of the developed CVM modification dependence of the gas flow on the pressure drop was obtained. Comparison results of the characteristics, obtained by CVM and data of CFD simulation are given in Fig. 8. Relative CVM results deviation from CFD solution does not exceed 3%.

Table 2. Comparison of MKO and CFD calculation results (α=30°, a/b = 0,6)

Pressure drop, MPa	Flow rate (CFD), m^3/days	Flow rate (CVM), m^3/days	Deviation, %
2	1963.206	1951.211	0.672667
4	2804.58	2719.75	3.024682
6	3367.6	3304.097	1.885714
8	3830.646	3793.354	0.973498
10	4254.227	4222.214	0.752495

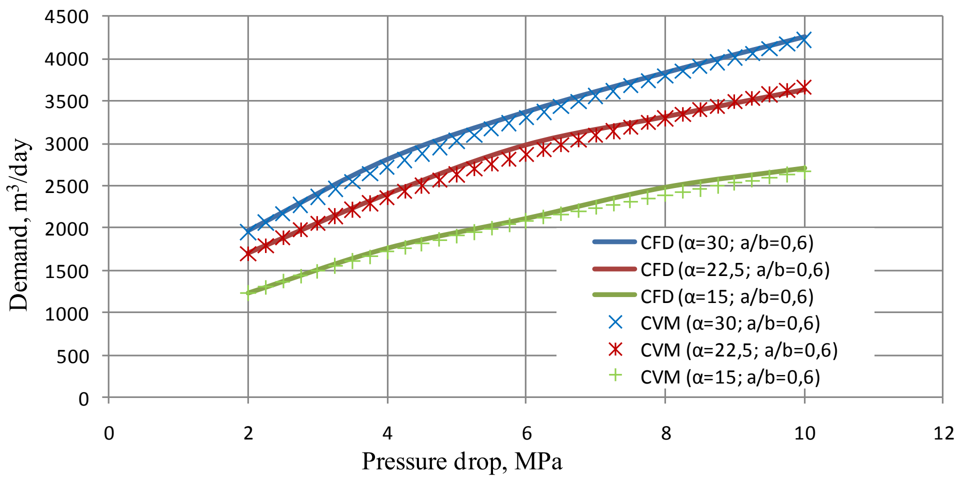

Fig. 8. Flow dependence on the pressure drop

4. Comparison of liquid and gaseous phases flow calculations

For every flow regulating device modification calculations based on CVM for various pressure drops at interval of 0.25 MPa were carried out. CFD simulation was used for adjustment and controlling the results obtained by CVM. With this purpose 3 CFD calculations were carried out every time for device pressure drops, corresponding the boundaries and the midpoint of the pressure drops considered range [5,6]. The duration of every problem CVM-simulation was about several seconds, while the duration of CFD-simulation was equal to more than four hours for very modification.

Volume flows for seal edge structures with edges space angle α=15° and relative edge height a/b = 0.7 for water and gas under formation conditions are given in Fig. 9. By formation, the following conditions are taken: pressure 14 MPa, temperature 343 K. Volume flows for seal edge structures with edges space angle α=15° and relative edge height a/b = 0.7 for water and gas under standard conditions are given in Fig. 10. As it can be seen from the results presented in figures, the considered structure of the device efficiently regulates the flow of the liquid phase and lets gaseous fluid pass almost unconstrained.

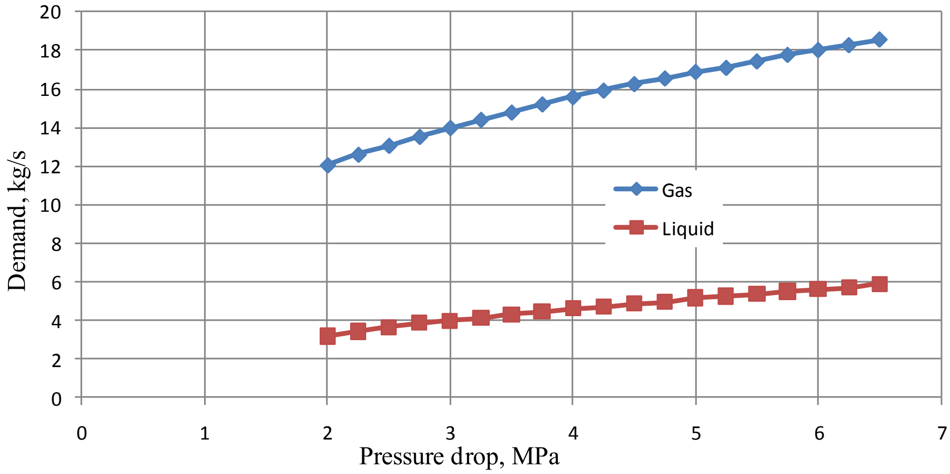

Fig. 9. Comparison of flow dependences on the pressure drop for gaseous and liquid operation media (α=15°, a/b = 0.7)

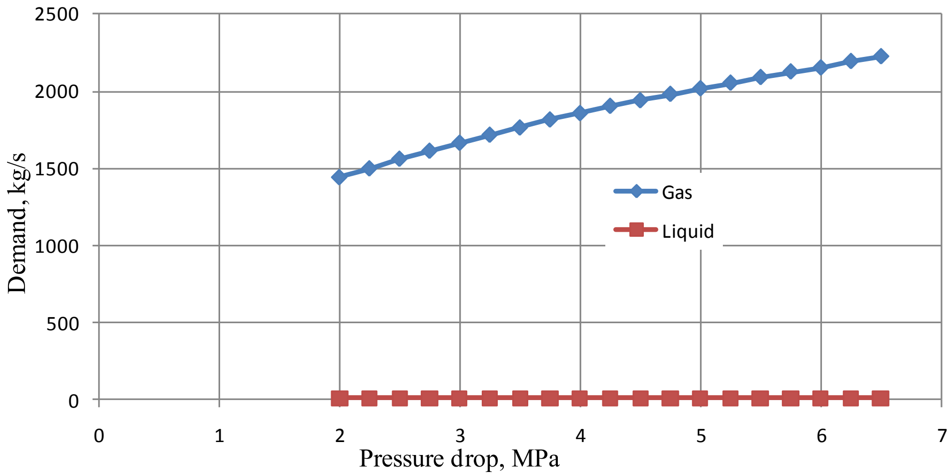

Fig. 10. Comparison of flow dependences on the pressure drop for gaseous and liquid operation media under initial conditions (α=15°, a/b = 0.7)

On the basis of the ~3000 calculation series, the design modification of seal edges with space angle α=15° and relative edge height a/b = 0.7 was chosen [10].

Thus, the calculations defining structural characteristics are carried out, on their basis, recommendations for the liquid phase flow regulating device design are suggested. Having labyrinth seal edges in the device leads to the reduction of its dimensions in comparison with similar structures [1].The considered structure can be used for the regulation of the liquid phase, while gas passes almost unconstrained. As a result, a liquid phase flow regulating device, providing minimizing of the liquid penetration into the gas producing system during gas formation breakthrough by displacing water, is developed.

5. Conclusion

With the help of CVM the numerical model of the liquid phase flow regulating device for the well fluid was developed, and alternative calculations corresponding various design modifications and modes of operation were carried out. Comparison and more precise defining of the regulating device numerical model (CVM) based on the CFD-simulations data were conducted. Cross-verification of the regulating devices calculating method using CFD simulation was carried out, where the average relative CVM deviation from CFD less than 3% was observed. On the basis of the calculation analysis the design of the liquid phase flow regulating device for the well fluid was developed.

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